Scenario-based forecast for the electricity demand in Qatar and the role of energy efficiency improvements*

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Abstract:

We model the electricity consumption in the market segment that compose the Qatari electricity market. We link electricity consumption to GDP growth and Population Growth. Building on the estimated model, we develop long-range forecasts of electricity consumption from 2017 to 2030 over different scenarios for the economic drivers. In addition, we proxy for electricity efficiency improvements by reducing the long-run elasticity of electricity consumption to GDP and Population. We show that electricity efficiency has a crucial role in controlling the future development of electricity consumption. Energy policies should consider this aspect and support both electricity efficiency improvement programs, as well as a price reform.

Keywords: electricity consumption, electricity efficiency, scenario-based forecast
JEL Codes: O13, Q47, C32, C53

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1. Introduction

In 1995 the State of Qatar adopted an ambitious development vision that has led to an extraordinary growth rate in real GDP and, consequently, in population. The real GDP growth rate was, on average, 15% per year from 2004 to 2016. In the same period, the average yearly population growth rate was 10%. Economic development and demographic growths have led to a relevant increase in electricity generation that showed an average yearly growth of 9.9% from 2006-2016. The increase in electricity generation is a response to the boom in electricity demand. In fact, electricity consumption reached unprecedented levels after 2010, attaining an average yearly growth rate of 16.9% from 2008 - 2016.[1] The difference between electricity demand and electricity generation is more than noticeable, leading to challenging energy policy issues.

In this regard, in 2013, the Qatar General Electricity and Water Corporation[2] (KAHRAMAA), an institution of the government of the State of Qatar, adopted a national program for energy conservation and energy efficiency improvement (TARSHEED). Focusing on the electricity demand side, we note that KAHRAMAA provides free electricity and water for Qatari residents (only for one house per Qatari). This is a critical aspect, as the existence of free electricity does not induce any energy conservation habits by Qatar inhabitants. Furthermore, the current electricity tariff benefit of subsidy in each market segment, leading to electricity prices being lower than the production costs per kWh. Such an energy policy has further negative impacts on both electricity consumption (as companies, SMEs, and households do not have incentives for controlling electricity consumption) and energy efficiency (as the possible reduction in electricity costs due to energy efficiency improvements is likely much smaller than the costs sustained for the efficiency improvements). Finally, to finance the subsidization program, KAHRAMAA pays the difference through the State of Qatar budget. Therefore, the absence of stimuli pushing for electricity conservation, and the combined existence of subsidies, lead to high costs charged to the public budget. From the supply side

[1] Computed by the authors based on the billing data at KAHRAMAA.
[2] KAHRAMAA is the only distributer of water and electricity in Qatar.

perspective, the Qatari government would like to sustain the increase in electricity generation given the expectations of positive trends in the economy and population growth for more than a decade, as part of the reform initiatives planned to reach the Qatar National Vision 2030 (QNV2030).[3] However, the simple increase in electricity generation might not be sufficient to respond to the increase in electricity demand and may lead to electricity shortage. One possible approach to control and manage the future evolution of electricity demand involves policies active on both the demand and production sides. While for the latter infrastructure projects are the only way, for the former, technological progresses might allow improved energy conservation. In fact, Wang et al. (2016) and Lorna et al. (2010) show that improving energy efficiency is one of the quickest and most cost-effective ways to control electricity consumption even accounting for the negative impact of the rebound effect.

Our study has several objectives. First, by building on a database of electricity consumption, based on billing data, we link the electricity consumption in each segment of the Qatari electricity market with a set of electricity consumption drivers. This allows for the designing of a model that is appropriate for long-run electricity consumption forecasts. Our data covers the period starting in 2008 and ending in the second quarter of 2017. We consider six market segments: the industrial sector, both the commercial and hotel services segments, the villa and flat residential segments, and the government sector. National electricity consumption depends both on the size of the economy and on the level of the population.[4] As possible drivers of electricity consumption, we consider the population level and the gross domestic product (GDP). Our choices are coherent with the economic theory and previous literature on the link existent between economic growth and electricity consumption. In fact, Masih and Masih (1996) provide evidence on the causal relationship between energy demand and economic growth for a group of countries. Wolde-Rufael (2006) studies the long-run and Granger causal relationships between per capita electricity consumption and real GDP finding mixed evidence on both the existence of long-run links and causality effects. Squalli (2007) analyzes

[3] Qatar National Vision 2030 (QNV2030) has been launched to serve as a clear roadmap for Qatar's future. The vision is a guide for the economic, social, and human environment for future decades.
[4] Electricity prices in Qatar are flat for all the sectors.

the relation between economic growth and electricity consumption in OPEC countries, showing some heterogeneity among countries. Ziramba (2008) finds that income is the main determinant of electricity demand, while electricity price is not significant. Inglesi (2010) indicates that there is a long-run relationship between electricity consumption and both electricity tariff and the economic growth, while the short-run dynamics of the system depend also on population growth. Finally, Payne (2010) provides a survey on the studies that analyze the nexus between GDP and energy demand (electricity consumption). The model we estimate, besides being consistent with the cited literature on the choice of economic drivers, also allows identifying the existence of both short-run and lung-run relations among variables. Further, it permits the estimation of the elasticities of electricity consumption with respect to both GDP and population.

Second, building on the estimated models, we develop scenario-based electricity consumption forecasts. The scenarios start in 2017 and end in 2030 to match the QNV2030 program horizon.[5] All scenarios focus on possible paths for both the GDP and the population growth. For these variables, we design alternative growth paths, centered on the actual growth rates. Moreover, we evaluate specific combinations of high and low growth rates to analyze their effects on electricity consumption.

Third, based on economics drivers, we add to the scenarios the possible effects linked to energy efficiency policies. In this respect, as our dataset does not contain variables linked to energy efficiency, we decided to proxy for energy efficiency changes by acting on the long-run elasticities. In fact, we postulate that an improvement in energy efficiency is reducing the impact of economic growth and population growth on electricity consumption. To our best knowledge, we are the first to follow such an approach in designing long-run scenario forecasts.

From an energy policy perspective, our research aims to quantify the potential economic benefits of improved electricity efficiency to stimulate the adoption of proper electricity consumption policies for Qatar. Our analyses cover different economic sectors and thus allow the design of sector-

[5] We adopt this forecast horizon to be consistency with the national vision of sustainable development and environment protection, as defined in the program QNV2030.

dependent policies with positive impacts on the Qatari economy. Improving electricity efficiency in the residential sector may contribute to improvements in the quality of residential services and to reduce poverty and social inequality, in particular for vulnerable households. By promoting electricity efficiency and electricity efficient products, municipalities can help Qatari residents reduce their annual energy bills. In this case, relevant policy instruments may include, as examples, electricity efficiency regulations for residential buildings, and energy labelling and certificate schemes for household devices (e.g. high efficiency bulbs, Energy Star for household's appliances as implemented by KAHRAMAA in Qatar).[6] Differently, the industrial sector is, in general, energy intensive, and thus of central interest in the design of energy efficiency policies. In this case, firm sizes tend to be a crucial factor in adopting electricity efficiency programs, since large firms are more open to electricity efficiency measures than are smaller firms. In particular, small- and medium-sized enterprises (SME) spend less on investments related to such electricity efficiency programs, while allocating fewer resources to improve their electricity efficiency outcomes. Therefore, energy efficiency policies should take into account those differences. As shown by Lorna et al. (2010), the range of estimates for the size of the rebound effect is very low to moderate. Therefore, technology policies (energy efficiency improvement policies) are some of the most relevant options available to control future electricity consumption.

The results of our study are also of interest under a different viewpoint. The empirical evidence support the existence of long-run relationships between electricity consumption growth, GDP growth and population growth in all the market segments characterizing the Qatari electricity market. And as expected, the elasticity of electricity consumption to GDP is larger in the industrial segment, followed by the services segments (commercial and hotel). Differently, the elasticity to population is larger in the residential segments (flat and villa) and not statistically significant in the industrial segment. This confirms the appropriateness of our modeling strategy and supports the

[6] There are several measures established in Qatar for consumer appliances (Air conditions, refrigerators, washing machines, high efficient light bulbs, etc.).

adoption of scenarios based on future paths for GDP and population. We stress that we do not include the electricity price in the model as the government controls the price with free electricity for residents and flat tariffs for expatriates, residents, business, hotels, and public services.[7]

When considering the scenario-based forecasts, we observe that future growth of electricity consumption, in the absence of energy efficiency policies, might really explode in some market segments. The consumption might reach critical levels in both the industrial and commercial sectors, while relatively lower paths characterize the residential segments. Nevertheless, the adoption of energy efficiency policies represents a crucial step toward the control of electricity consumption, as it will be combined with the energy production level in Qatar.

This last aspect is consistent with the impact on electricity consumption of the simulated effects of energy efficiency policies. In fact, when we proxy energy efficiency improvements by reducing the long-run elasticities, we observe a clear reduction in electricity consumption levels. Therefore, the introduction of energy efficiency policies represents a fundamental element in future energy policies of Qatar. In fact, our scenario-based forecasts show that a 5% improvement in electricity efficiency leads to a relevant contraction in consumption compared to cases where electricity efficiency improvements are not considered. In particular, we observe a consumption reduction of 52% in the industrial segment, 42% in the commercial segment, 27% and 14% in the two residential segments (villas and flats, respectively), 19% in the hotels segment, and 5% in the government segment.

The paper proceeds as follows. Section 2 provides a detailed description of Qatar's electricity market and of the data we use in our analyses. Section 3 introduces the econometric methodology, while Section 4 describes the scenarios. Section 5 analyzes the electricity consumption levels obtained by combining the estimated model with the scenario, and Section 6 concludes and provides policy recommendations.

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[7] For details on tariffs, see http://www.km.com.qa/CustomerService/Pages/Tariff.aspx.

2. Data description and preliminary data transformations

2.1 Qatar's electricity market and electricity consumption data

The electricity market in Qatar is demand-oriented; it always tries to satisfy the demand created by various sectors of the Qatari economy. The market is expanding at a fast pace due to a huge economic and population expansion, with sensible growth in heavy industries. In 2016, we observed the historical peak electricity demand, with a value equal to 7,435 MW, with a 2.3% growth compared to the 2015 values. In 2016, the largest demand was that of the industrial sector, reaching 1,560 MW, but with a small 0.1% increase with respect to 2015 demand. The total electricity transmitted in 2016 was 39,667 GWH with a growth of 2.1% in 2015. Manufacturing and residential sectors are growing every year, following the socio-economic development of Qatar. From a different viewpoint, Qatar is a member of the Gulf Cooperation Council International Authority (GCCIA). This organization aims at building and improving the interconnection capacity between the power grids of member countries for better energy distribution. The existence of high interconnection capacity also affects the demand and supply equilibrium and helps to avoid temporal imbalances. Interconnection between grids experienced two phases: a first phase interconnected Kuwait, Saudi Arabia, Bahrain and Qatar; the second phase focused on internal integration of the UAE and Oman power systems. Currently a third phase is in progress, for interconnecting the two clusters created in the first and second phases. Moreover, the first phase countries have recently engaged in power exchanges. Future projects include the creation of a regional power market exchange. The Qatari electricity market is a fast-developing market with several infrastructural improvements planned in future years.

With respect to the supply side, the power generation in Qatar is both public and private. In fact, there are several private power generation companies operating under the government supervision. The installed electricity power generation is currently able to satisfy the electricity demand of the Qatar economy, but the fast growth of the economy and of the population represents relevant challenges for the future energy policy of the country. Further, we have to combine this evidence with the fact that the government of Qatar provides subsidies for water and electricity for expatriates and provides free water and electricity for its citizens. Therefore, the current work, by providing a comprehensive framework for estimation and forecasting of the electricity demand in Qatar for relevant economic sectors, will provide the government relevant information to design both the short and long run energy policies for both the supply side and the demand side. Our study will focus on electricity consumption that represents the main dependent variable. By providing long-run forecasts of electricity consumption, we will be able to identify future imbalances between the supply and the demand of energy in the absence of conservation and efficiency policies.

The Qatar General Electricity and Water Corporation, "KAHRAMAA," has kindly provided the basic electricity consumption data we use in our analyses. The data are available at the monthly frequency, starting in January 2008 and ending in June 2017. The time series consists of the electricity consumption levels in KW as recovered from a billing database.[8] Therefore, they might be subject to distortions due to the misalignment between the consumption period and the billing period. Figure 1 reports the decomposition of electricity consumption by market segment, based on the original unadjusted monthly time series. The segments are Commercial (COMM) that includes SMEs, banks, and financial services, Flat (FLAT), Government (GOV), i.e. public offices, ministries, and public schools and universities, Industrials (IND), Hotels (HOTEL) and Villas (VILLA). We note that the residential electricity consumption is equal to the sum of two market segments, FLAT and VILLA. Further, we note that some industrial companies (included in IND) are also active on electricity production and produce power for their own needs. From Figure 1 it emerges that two segments are extremely relevant in terms of electricity consumption, i.e. VILLA and COMM. Each of them represents more than 25% of yearly consumption with a relatively stable level over years. In terms of relevance, the third segment is the IND one, followed by GOV and FLAT. The HOTEL segment

[8] Several private entities generate electricity under one umbrella, the Qatar Electricity & Water Company, which operates under the supervision of the government. KAHRAMAA buys electricity from the generators and distributes them to each end user (including government, residential, industries and the commercial and services sectors). The billing database includes data on the electricity consumption of each end user inside Qatar.

is the last one in terms of the yearly fraction of total electricity consumption. Notably, the GOV and IND segments experienced relevant changes in their contribution to total consumption. While GOV accounts for 20%-25% in 2008-2009, we observe it decreases to 15% in the most recent years. However, IND sensibly jumps and takes a relevant role from 2010-2011, when it accounts for more than 25% of total consumption and then stabilizes in recent years to around 20%. These patterns are consistent with the development and industrialization paths of the Qatari economy.

Figure 1: Decomposition of electricity consumption by year (in percentage). Yearly total electricity consumption is the sum of monthly electricity consumption data provided by KAHRAMAA. We do not report the decomposition for 2017 as we only have data for the first semester of that year.

Figure 2 contains the time plot of the electricity consumption for each market segment and for the total (i.e. the sum of the six segments). The simple visual inspection of the data reveals some peculiar features. Commerce, Flat, Hotel and Villa have a clear periodic pattern, while Government has a less evident seasonal behavior. Differently, Industry has a less regular evolution. In some cases, especially for Flat, Hotel and Villa, as well as for Government, the periodic behavior has some breaks or unexpected movement.

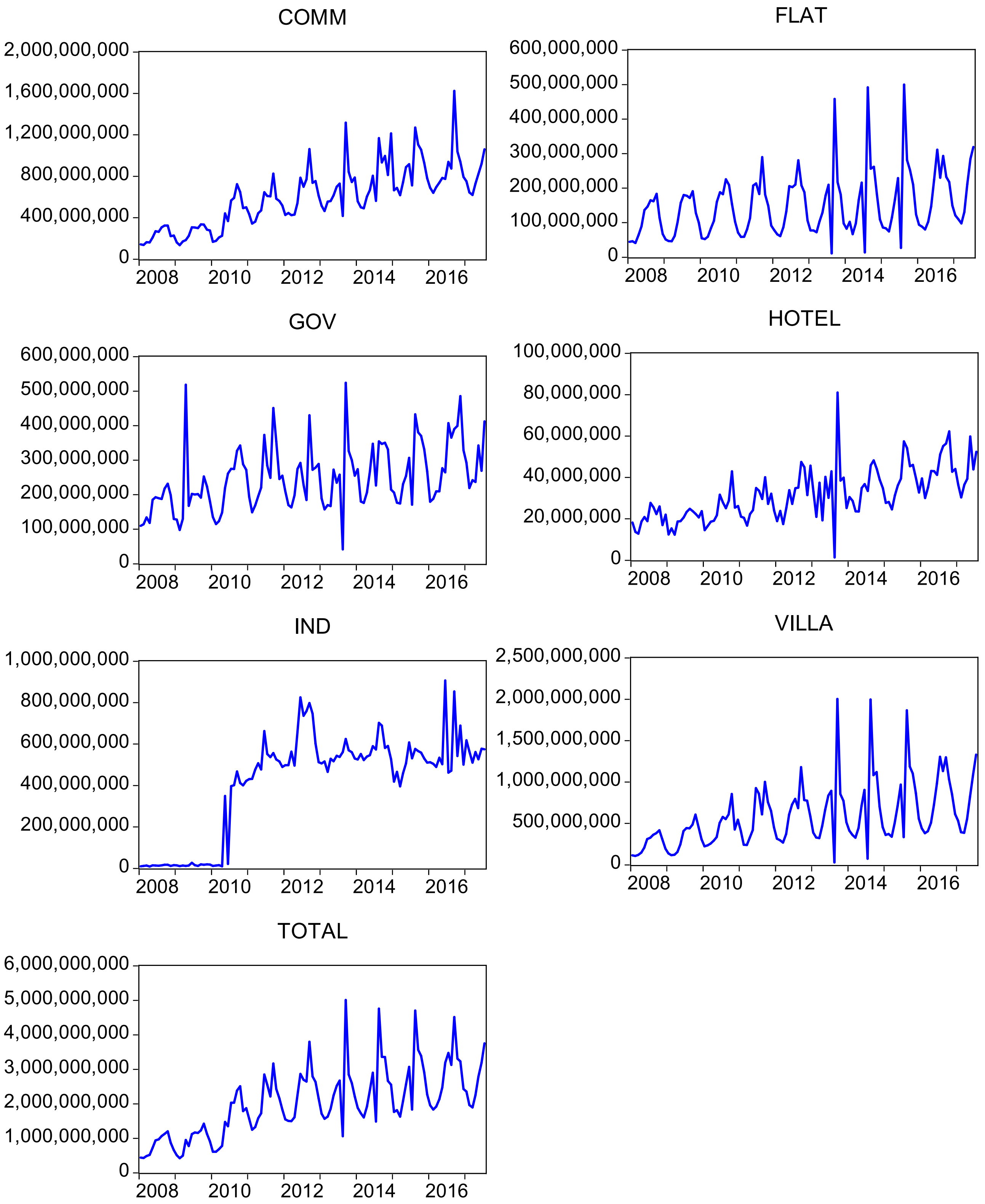

Figure 2: Electricity consumption levels (in kWh) over time and across market segments from January 2008 to June 2017. The total is the sum of the six market segments.

Moreover, it clearly emerges that the Industry time series has a break in 2010 and a clear change in its structure. Similar problems, although less extreme, appear in the cases of Commerce, Hotel and Villa, as well as in the other market segments. The total time series, being the sum of the segments, inherits the behavior of the underlying components. We might link, at least in part, these changes to the fast development of the industrial sector and the increase in the population observed from 2010 onward.[9] This might affect the identification of a modeling strategy for forecasting electricity consumption.

While for the supposed break in the first part of the series, we might limit the sample for the analyses and focus on the data from the second half of 2010 onward, we suggest taking appropriately into account the presence of irregular behaviors in the seasonal pattern with a statistical procedure. In fact, by looking at the quarterly time series, obtained by aggregation of the monthly figures, the periodic pattern appears to be regular in all cases. Consequently, we postulate that the odd patterns observed in the monthly time series are a consequence of a misalignment between billing and consumption. Therefore, to develop models based on the monthly time series, the data require a preliminary adjustment step based on statistical reconciliation procedures. Appendix A discusses a possible approach for the adjustment of monthly data. However, preliminary analyses demonstrate that the monthly frequency does not represent an optimal choice for our purposes for two reasons. First, at the monthly frequency we do not have access to monthly figures of possible economic drivers for long-run scenario-based forecasts. As we will discuss in the following section, the only relevant economic driver available to us is the real GDP, available at a quarterly frequency. One might object that electricity consumption also depends on other variables such as temperature and humidity. However, the available weather variables, mostly capture the seasonal variation in the electricity consumption time series and are not characterized by a time trend, whose role is crucial in the development of long-range scenario-based forecasts.

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[9] The State of Qatar focused a significant effort of development in each aspect of the economy to meet the expectation of Qatar National Vision 2030 and to prepare for World Cup 2022.

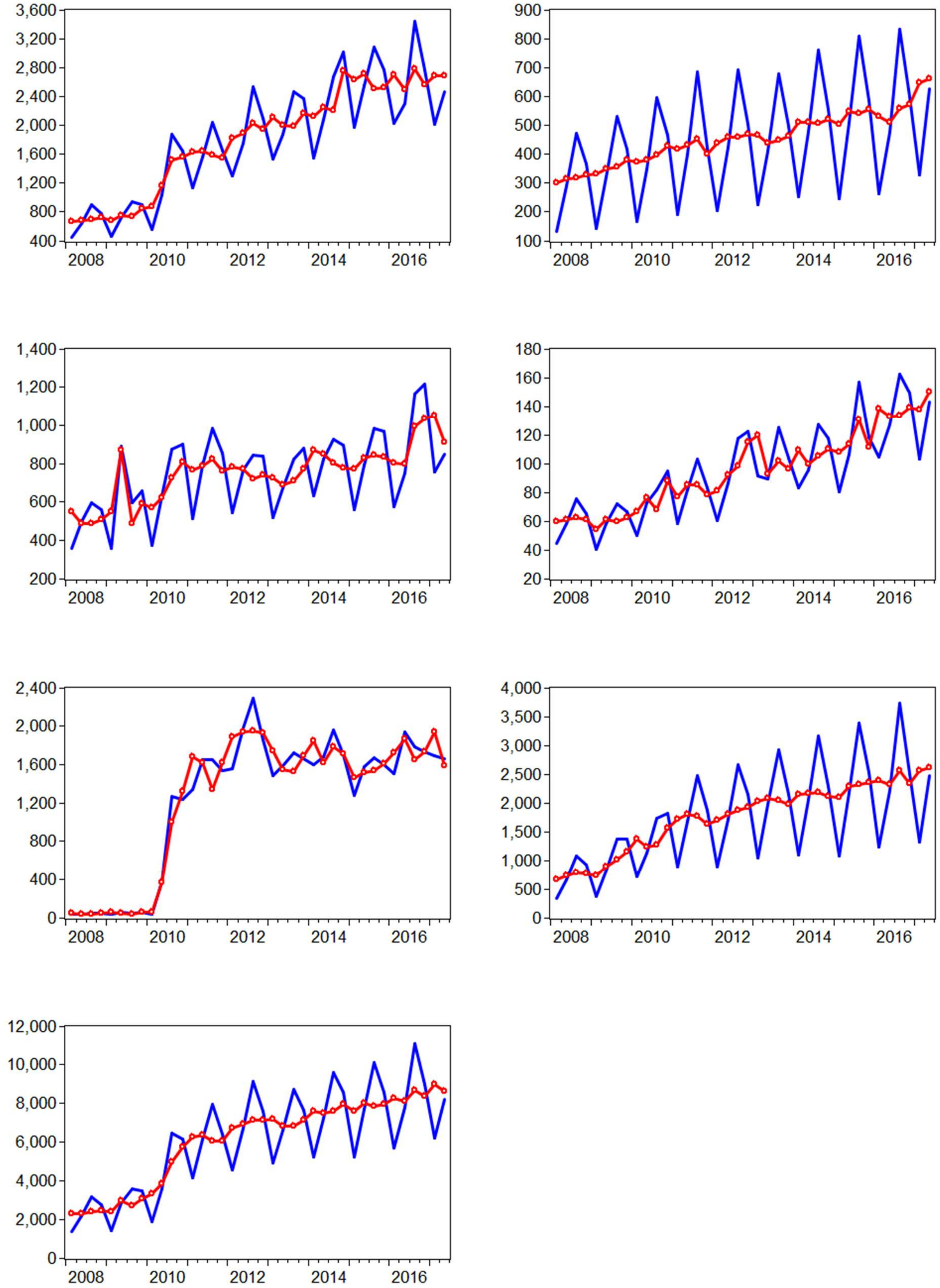

Figure 3: Quarterly time series of electricity consumption (in Millions of kWh) obtained by simple sum of monthly figures (in blue), and the Quarterly seasonally adjusted data (see Section 2.2 – in red with circles). The total is the sum of the six segments.

Consequently, we decided to work only with quarterly figures. The quarterly electricity consumption data correspond to the aggregation of monthly figures within each quarter. Figure 3 reports the quarterly time series where the presence of a seasonal pattern emerges in most cases. Finally, we note that the joint availability of monthly and quarterly data could call for the use of mixed frequency models, see Ghysels et al. (2007), among many others. However, the presence of unit roots and cointegration would make the analysis quite complex, and we decided to leave this aspect for future researches.

2.2 Data cleaning and preliminary analyses

To develop long-run, scenario-based forecasts, we also decided to work on seasonally adjusted, quarterly time series. Such a preference stems from the need of obtaining forecasts not affected by the seasonal variation and that might benefit for the availability of macroeconomic, seasonally adjusted, drivers. One might object that we could reach the same objective by working directly on yearly data. However, the Qatar time series are excessively short to build a forecasting model based on yearly aggregates. Further, given that scenario forecasts will be based on possible future evolutions of the growth rates of relevant economic drivers, we decided to apply a log transformation to the variables of interest, thus with the possibility of interpreting the first difference of relevant variables as growth rates.

We remove the periodic patterns by means of TRAMO-SEATS (see Gomez and Maravall, 1992, 1994, 1996, 2001, Gomez, Maravall and Pena, 1999, for TRAMO and Cleveland and Tiao, 1976, Box, Hillmer and Tiao, 1978, Burman, 1980, Hillmer and Tiao, 1982, Bell and Hillmer, 1984, Maravall and Pierce, 1987, and Maravall, 1988, for SEATS). We note that, by seasonally adjusting the series with TRAMO-SEATS we are preserving the yearly consumption level, in line with the possibility of easily recovering yearly aggregates when focusing on scenario-based forecasts. See

Figure 3 for a plot of the seasonally adjusted quarterly time series of electricity consumption by market segment.

On the adjusted series, we first test for the presence of a unit root, accounting also for the possible presence of a linear deterministic trend, using three standard tests: The Augmented Dickey-Fuller, the Phillips-Perron, and the KPSS tests. Table 1 reports the results of these various tests.

Table 1: Unit root tests

	ADF	PP	KPSS
COMM	0.431	0.906	0.191^{b}
FLAT	0.155	0.083	0.132^{b}
GOV	0.105	0.007	0.125^{b}
HOTEL	0.003	0.003	0.085^{c}
IND	0.438	0.916	0.166^{b}
VILLA	0.000	0.001	0.181^{b}
GDP	0.730	0.491	0.169^{b}
GDP oil	0.071	0.625	0.165^{b}
GDP non-oil	0.650	0.539	0.171^{b}
Expenditure	0.000	0.003	0.171^{b}

For the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, we report p-values for testing the null hypothesis of a unit root. The test equation has been specified according to the AIC criterion and checking for the presence of deterministic terms. For the KPSS test we report the test statistic for verifying the null hypothesis of stationarity. We indicate with a *b* a rejection of the null at the 5% confidence level and with *c* a rejection of the null at the 10% level. The critical values are 0.216, 0.146 and 0.119 at the 1%, 5% and 10% confidence level, respectively, including both intercept and trend.

Results in Table 1 show that COMM, FLAT, and IND electricity consumptions are clearly non-stationary as all the tests are concordant at the 5% confidence level. For GOV, two tests identify a unit root, while for HOTEL, all the tests suggest stationarity at the 5% confidence level, and for VILLA, two tests suggest stationarity. We thus have evidence of different behaviors of electricity consumption time series across the market segments. On the one side, four segments seem to be characterized by non-stationary behaviors, COMM, FLAT, GOV and IND. On the other side, for two segments, HOTEL and VILLA, we have some evidence of stationarity. However, we stress that these series are relatively short, with an overall length of 36 observations. Moreover, the relevance of the VILLA segment in terms of relative electricity consumption (see Figure 1) calls for accurate analyses and considerations when designing and building the long-range, scenario-based forecasts.

To provide scenario-based forecasts, we consider a set of possible exogenous economic and demographic drivers of electricity consumption. The first we consider is the population. We collect population data from the statistical reports of the Qatar Ministry of Development Planning and Statistics. Starting from yearly figures of the Qatari population, and using a polynomial spline function, we recover the quarterly pattern for the population evolution from 2008 to 2016, which we report in Figure 4. We observe how the population nearly doubles in ten years, moving from 1.4 million in 2008 to 2.65 million in 2016. This increase is clearly at least partially responsible for the increase in the electricity demand coming from the residential segments.

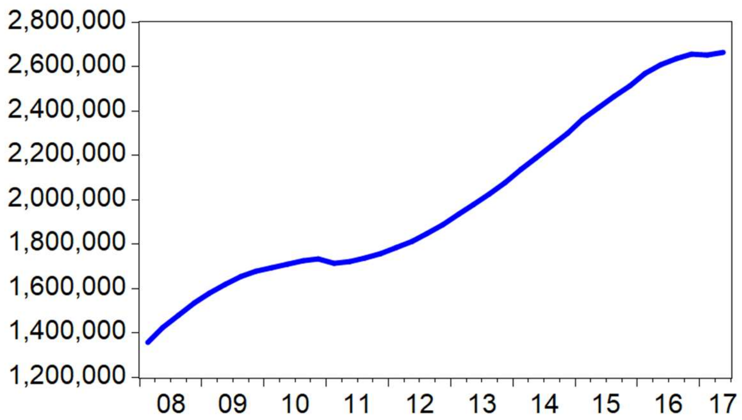

Figure 4: Qatari population (inhabitants) evolution from 2008 to 2016 (over quarters).

The second driver we consider is the real gross domestic product (GDP), which is available at the quarterly level, and decomposed with respect to its either oil-related or non-oil related origin. Furthermore, we also consider the data on government expenditure, which might affect the electricity demand as it represents a stimulus to the development of specific economic sectors in Qatar. Figure 5 reports the evolution of those variables. Notably, government expenditure presents some spikes, which is partly explained by the infrastructure projects that began in 2010. In addition, the oil-related component clearly drives the overall GDP pattern and is dependent on the oscillation of the oil price. We also observe how the non-oil fraction of the GDP steadily increased from 2008 becoming more relevant than the oil-related GDP fraction in the most recent years.[10] Table 1 reports unit root tests for the economic and demographic drivers. From the table, we observe that these variables also show evidence of non-stationarity. We note that, in accordance with the electricity consumption, we work with the logs of all variables.

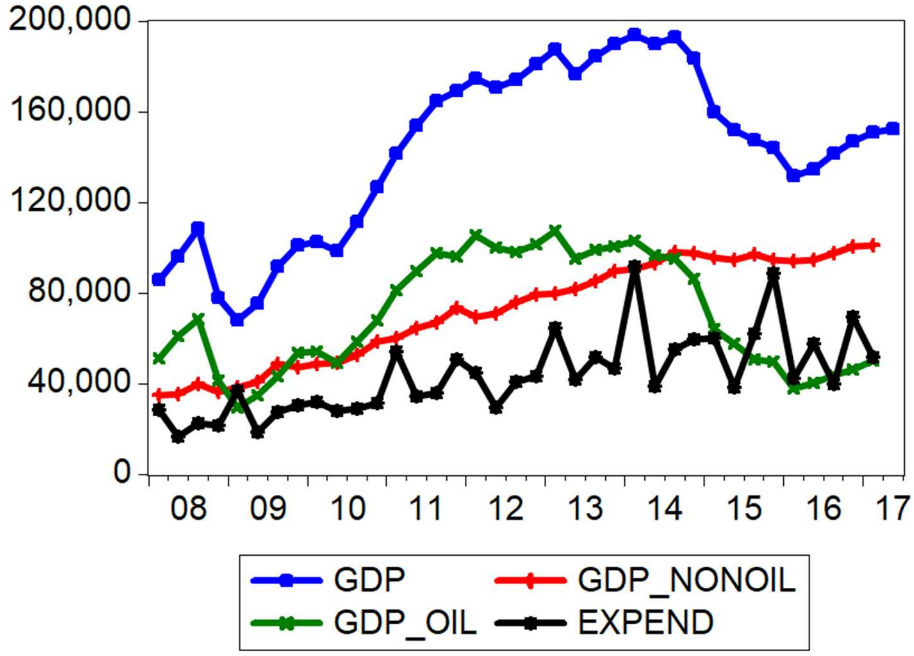

Figure 5: Quarterly evolution of GDP (also split into Oil and Non-Oil related) and government expenditure.

3. Modelling strategy

We now focus on the statistical models we might consider for explaining the electricity-consumption segment patterns as functions of their own past values (i.e. capturing their own

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[10] Qatar's economy is oil-based, and government revenues from oil and natural gas account for more than 85% of the total revenues. Qatar owns the third-largest reserves of natural gas in the world. It is first in the world in producing liquefied natural gas and has the highest market share of natural gas extraction in the world. The State of Qatar has experienced a big jump in GDP due to the extraordinary revenue of oil and natural gas once the oil price spiked to above $100 USD per barrel during the period 2008- 2014. The recent price contraction has negatively affected the oil-related GDP.

dynamics) and with the possible role played by economic drivers. Given the evidence of non-stationarity in several segments of electricity consumption, and given the non-stationarity of the economic and demographic drivers, we cannot exclude the possible presence of cointegration between the variables. Therefore, to provide a general framework suitable for capturing, at the same time, non-stationarity and cointegration, and to allow interpreting coefficients as elasticities (either for the long-run and/or for the short-run), we opt for an error-correction representation (ECM) of an auto regressive distributed lag model (ARDL). Similar models are relatively common in the energy economics literature. Halicioglu (2007) uses an ARDL to analyze residential electricity consumption. Jiang and Li (2012) consider the long-run relation between energy demand and several other factors. De Vita et al. (2006) estimate an ARDL model and then consider the possible presence of cointegration among the variables rewriting the model into an error correction representation. Zachariadis (2010) focuses and on an ARDL model for three sectors of the Cyprus economy (residential, commercial and industrial). Amusa et al. (2009) and Shahbaz et al. (2013) focus on ARDL specification consistent with the existence of a cointegrating relation. In a similar setting, Badr and Nasr (2001) provide an evidence of the existence of long-run (cointegrating) relations between energy consumption and weather-related variables in Lebanon. Notably, the model adopted by Basr and Nars (2001) allows testing for cointegration even when it is not certain that the underlying variables are either first difference stationary or trend stationary. The bound testing approach, proposed by Pesaran and Shin (1999) and Pesaran et al. (2001), fits our framework where we do have cases where, for some of the variables of interest, the unit root tests we consider are not all concordant. As an example of the application of the bound testing approach in the energy economics field, we cite Narayan and Smyth (2005).

Following the ARDL model; let y_t^i be the log-electricity consumption in quarter t and market segment i. Moreover, let the vector x_t contain the logarithms of the economic and demographic drivers (GDP, or Expenditure, or GDP split into oil and non-oil, and Population). The ECM representation of the model, following Pesaran et al. (2001) reads as

$$\Delta y_t^i = \alpha + \pi_y y_{t-1}^i + \pi_x' x_{t-1} + \sum_{j=1}^{p} \vartheta_j \Delta y_{t-j}^i + \sum_{j=0}^{p} \varphi_j \Delta x_{t-j} + \varepsilon_t \quad (1)$$

where we introduce a drift α, the parameters π_y and π_x' are the long-run multipliers (or long-run elasticities), the long-run (cointegration) relation equals $\alpha + \pi_y y_{t-1}^i + \pi_x' x_{t-1}$, the lags of Δy_t^i and the contemporaneous and lagged values of Δx_t determine the short-run behavior of electricity consumption, and ε_t is an error term. Coefficients of the lagged variables represent the short-run elasticities. For simplicity, when we focus on elasticities we will always refer to the long-run elasticities, i.e. the long-run multipliers.

As discussed by Pesaran et al. (2001), testing for the absence of cointegration correspond to a test for joint null hypotheses, $\pi_y = 0$ and $\pi_x' = 0$. Note that the alternative hypothesis covers all the cases where at least one of the parameter sets is different from zero. Therefore, if we reject the null hypothesis, we cannot exclude the existence of degenerate level relationships between the variable of interest, y_t^i, and the drivers in x_t. We thus follow Pesaran et al. (2001), and first test the null hypotheses, $\pi_y = 0$ and $\pi_x' = 0$. If the null is rejected, we test $\pi_y = 0$. If the latter hypothesis is also rejected, we have evidence of a long-run level relationship between the variables. To verify both hypotheses, we compare the test statistics, built as a traditional F-test for coefficient restrictions, with critical value bounds, i.e. an upper bound and a lower bound. This allows distinguishing between three cases: falling between the bounds leads to a non-conclusive result; above the upper bound signals the existence of level relationships between first difference stationary variables, thus rejecting the null hypothesis, while falling below the lower bound leads to accepting the null hypothesis and the variables are stationary. To identify the presence of a cointegration relation between the variables, we thus search for a rejection of both the null hypotheses.

In our case, we specify the model in (1) allowing for a maximum of 4 lags (i.e. one year) given the limited sample size, from 2008 to 2016, at the quarterly frequency for a total of 36 observations.

We also allow for an intercept in the model, which makes it consistent with the possible presence of a linear trend in the electricity consumption variables. To determine the most suitable model specification, we follow a general-to-specific approach removing from the model variables that were not statistically significant at the 5% confidence level. The only exception is the IND time series. In that case, we chose a relatively high confidence level, 10%, given the need of further reducing the time series length, dropping the data of 2008, 2009 and the first quarter of 2010, due to the evident change in the series structure.

Table 2 reports the estimated test statistic for verifying the null hypotheses, $\pi_y = 0$ and $\pi_x' = 0$, and when it is rejected also the test statistic for the null hypothesis, $\pi_y = 0$. The table reports in the caption the bounds for verifying the null hypotheses. In all cases, we use the population and the GDP as conditioning variables. We also considered alternative specifications where we replaced the GDP with government expenditure or where we split GDP into the oil and non-oil related components, or, finally, where we used only the oil related or the non-oil related GDP. Overall, the specification with the total GDP provided the most relevant and coherent results. Additional estimates are available upon request.

Table 2: Bound testing for the existence of level relationships

	$\pi_y = 0 \cup \pi_x' = 0$	$\pi_y = 0$
COMM	22.77	-4.29
FLAT	45.24	-6.64
GOV	31.96	-4.59
HOTEL	15.82	-3.89
IND	21.78	-4.62
VILLA	53.97	-3.60

Bounds for the null hypotheses, $\pi_y = 0 \cup \pi_x' = 0$: 1% confidence level, lower bound (below this level, we accept the null hypothesis and the variables are I(0)) 5.15, upper bound (above this level, we reject the null hypothesis and the variables are I(1)) 6.36; 5% level, lower bound 3.79 and upper bound 4.85; 10% level, lower bound 3.17 and upper bound 4.14. Bounds for testing the null hypothesis $\pi_y = 0$: 1% level, lower bound (below this level we accept the null hypothesis and there is no level relationship among variables) -3.43, and upper bound (above this level we reject the null hypothesis and there exist a level relationship among variables) -4.11; 5% level, lower bound -2.86, and upper bound -3.53; 10% level, lower bound -2.57, and upper bound -3.21 see (Pesaran et al. (2001)).

Results in Table 2 highlight that, despite the possible heterogeneity that could characterize the electricity consumption in the market segments, the dynamic behaviors are similar. In fact, all series show evidence in favor of cointegration with population and GDP growth. These findings provide a clearer view on the stationarity properties of the series and should not be read as inconsistent with the results of the unit root tests, as the latter were simply not concordant. Building on the bound test results, we proceed with the analysis of long-run multipliers, which we report in Table 3.

Notably, the coefficients of the long-run multipliers have the expected signs, being all positive. This implies that an increase in either the population or the GDP will lead to an increase in electricity consumption. Clearly, the impact is heterogeneous across market segments. We first note that the elasticity of IND electricity consumption to population level is not statistically significant. We read this result in the light of two elements: First, the limited sample size that could have an impact in the estimation of the real link between population growth and industrial electricity consumption, and second, due to the policies implemented by the Qatari government. The stimulus to the industrial developments and the infrastructural projects currently under development might strengthen the link between population and industrial electricity consumption. This link could emerge in the long run and in future years, elements that are not yet reflected in the sample we use for estimation. The elasticity of GOV to GDP is also not statistically significant. Therefore, the change in the government-based consumption of electricity is not affected by the economic growth, but only by the population growth. This is somewhat expected as government electricity consumption covers a range of services offered to the population and is thus reacting to changes in the population level rather than to changes in the overall economic growth of the country.

Focusing on the statistically significant elasticities, and starting from the reaction of electricity consumption to GDP, we note a much larger impact on the IND segment, followed by the COMM. This is expected and is due to the strong link between the GDP and the oil sector. The FLAT segment follows, while the HOTEL and VILLA segments have the smallest elasticity values. Moving to population, we observe a larger impact on the FLAT and COMM segments followed by HOTEL and

GOV. This is consistent with the population growth after 2011 and the preparation of the takeoff stage in the development of each sector in the society in particular the infrastructure. The VILLA segment is, overall, the less sensitive to population.

Table 3: Estimated long-run multipliers (elasticities)

	GDP	POP
COMM	0.572	1.017
	(0.160)	(0.282)
FLAT	0.468	1.518
	(0.079)	(0.242)
GOV	*0.006*	0.727
	(0.083)	(0.163)
HOTEL	0.182	0.824
	(0.090)	(0.244)
IND	0.738	*0.317*
	(0.292)	*(0.201)*
VILLA	0.272	0.513
	(0.119)	(0.207)

The two columns report the coefficients included in π_x'. Within parentheses, we report the standard error of the estimated coefficients. In italics, we highlight the coefficients that are not statistically significant at the 5% confidence level.

4. Electricity efficiency, GDP and Population Scenarios

The main purpose of this study is to analyze the future paths of electricity consumption conditional to a set of possible scenarios for some of its relevant drivers. On the one side, we do have the economic drivers, proxied by the GDP growth, and the population growth. On the other side, we focus on the improvement in the energy efficiency, an element that could sensibly influence future paths of electricity consumption. We first consider the scenarios of the economic and population drivers. These two variables enter the model specified in the previous section and allow deriving the future paths of electricity consumption. If we have a sample size of T observations, and we do have a future path for the economic drivers, i.e. the variables included in x_t, from time $T+1$ to $T+M$, the future path of the electricity consumption levels at time $T+l$, for $l=1,2,\dots,M$, in a given market segment, i, denoted by Y_{T+l}^{i}, derive from the following equations

$$\widetilde{\Delta y_{T+l}^{i}} = \hat{\alpha} + \widehat{\pi_{y}}\widetilde{y_{T+l-1}^{i}} + \widehat{\pi_{x}^{\prime}}x_{T+l-1} + \sum_{j=1}^{p}\widehat{\vartheta_{j}}\widetilde{\Delta y_{T+l-j}^{i}} + \sum_{j=0}^{p}\widehat{\varphi_{j}}\Delta x_{T+l-j} \tag{2}$$

$$Y_{T+l}^{i} = \widetilde{Y_{T+l-1}^{i}}e^{\widetilde{\Delta y_{T+l}^{i}}} \tag{3}$$

where hats denote estimated values (of coefficients) and tilde denote scenario-based forecasts for the variables of interest (with the usual convention that if $T+l-j<T+1$ we do not have forecasts but observed values).

We design several scenarios for the GDP growth from 2017 to 2030, our long-run horizon. For the estimation of the models, we use data up to 2016. This is due to the absence of population data and incomplete GDP data for 2017 Therefore, in designing the scenarios, we consider quarterly growth rates from the third quarter of 2017 up to the fourth quarter of 2030. The quarterly growth rates of the scenarios are varying over time and correspond to different views on the GDP growth. Figure 6 reports the evolution of the GDP scenarios in terms of quarterly growth rates. The first scenario, Scenario 0, allows for a relevant and steady increase in the GDP, which we fix at the 1.5% per quarter. Scenario 1 is even more positive with a GDP growth that begins at the 2% level in each quarter before reducing to 1.5%. The following scenarios all have a positive view on the GDP, always growing, but with an intensity smaller than that characterizing Scenario 0. In Scenario 2, we mimic the pattern of Scenario 1 but starting at 1.5% level. In Scenario 3, after a few quarters with a 2% growth, GDP gradually reduces before stabilizing at the 1% level. Finally, Scenario 4 is similar to Scenario 3 but with smaller levels of GDP growth. These different scenarios might be associated with different views on oil price movements, accompanied by the potential increase in non-oil related sectors of the Qatari economy. On the one side, the increase in oil prices could sustain GDP growth, while, on the other side, the non-oil economy might smooth or balance the oil price decrease, as in most recent years.

Similarly, to the GDP case, we design scenarios for the population evolution. We consider again five different scenarios with similar patterns but differing in terms of the population growth; see Figure 7. The population scenarios include the first five years of larger population growth compared to the reduced growth in the following eight years. The baseline scenario for population growth, Scenario 0, mimics the population growth forecasts of the Internal Strategic Planning Forum of the State of Qatar, which predicts a population growth of about 5% until 2022 and growth at the 3% rate from 2023 to 2030. The other four scenarios we consider simply modify the baseline scenario by scaling up or down the growth rates of the baseline scenario. We increase/decrease by 1% or 2% the population growth in the years 2017-2022, and by 0.5% or 1% the growth in the years 2023-2030.

We now consider the design of scenarios for the energy efficiency level. In our models, we do not have an economic driver that monitors energy efficiency. Therefore, changes in efficiency will not be proxied by a change in a reference variable. Differently, we assume that changes in energy efficiency impact on the long-run elasticities, i.e. on the coefficients included in π_x' in equation 1. In fact, those coefficients represent the impact of the changes in GDP and population on the electricity consumption. Increases in energy efficiency will lead to a smaller impact of GDP or population growth on the electricity consumption. In this case, we associate scenarios with a percentage decrease in the long-run multipliers. Therefore, we consider the baseline scenario, where energy efficiency is not affected, and three scenarios associated with a 1%, 5% or 10% decrease in both long-run multipliers. Such a choice is clearly limited and does account for possible heterogeneity in the improvement of energy efficiency across the different market segments. Moreover, we do not account for rebound effects given that improvements in energy efficiency might be offset by an increase in propensity to consume electricity. Within our simulation framework, as the changes in energy efficiency are not immediate, that is they do not lead to an immediate decrease in elasticities, we assume that the decrease in the elasticities is distributed over years. For the first scenario, we allow for a decrease in the multipliers at a rate of 0.2% per year for 5 years. Similarly, in the second case, we consider a decrease in multipliers at a rate of 1% for 5 years, and in the third case, a decrease in the multipliers at a rate of 1% for 10 years. In all cases, the decrease of the multipliers will start in 2019, as energy efficiency improvements need some time to produce effects on the electricity consumption.

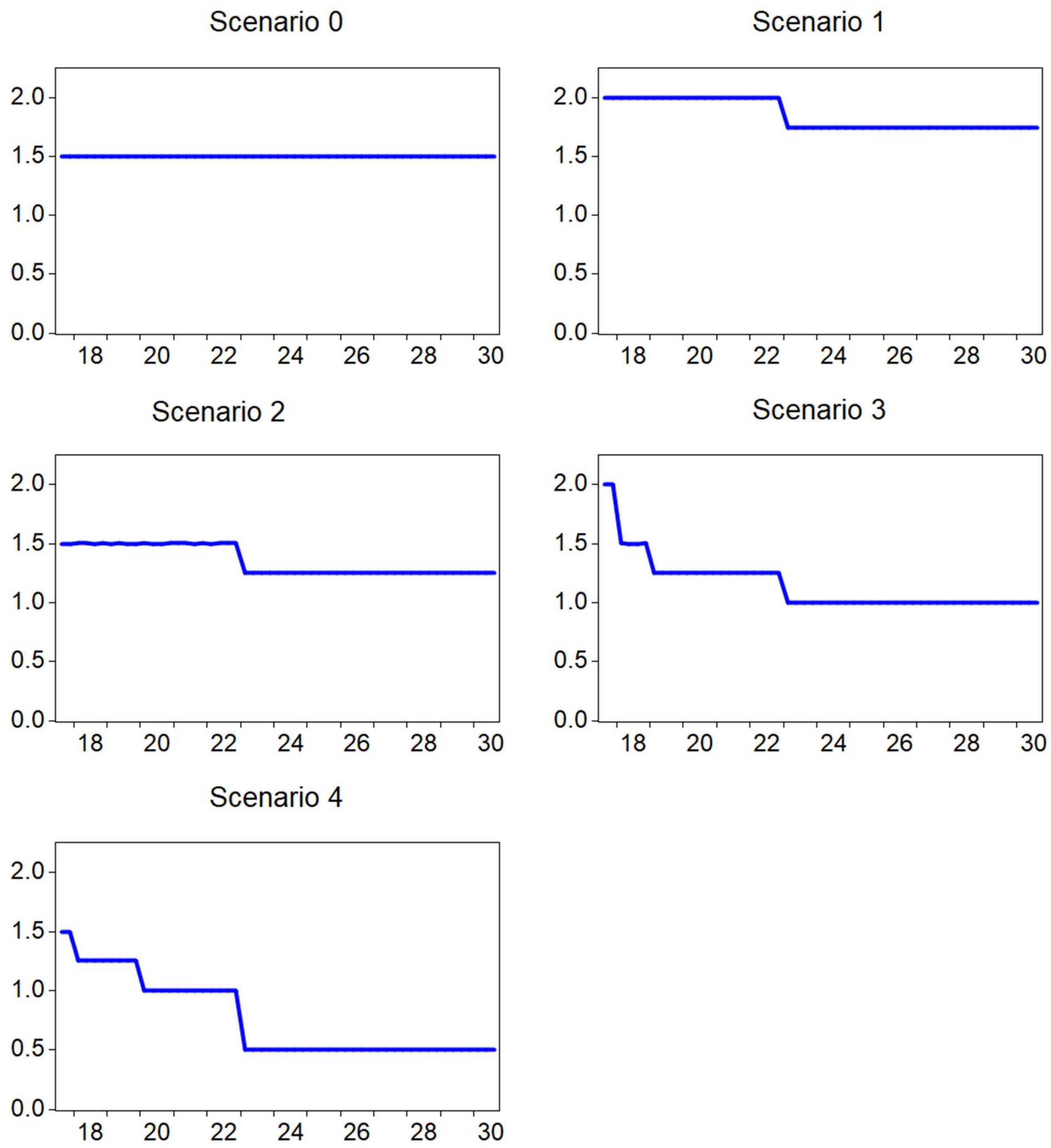

Figure 6: GDP scenarios in terms of quarterly growth rates. Scenario horizons start in the third quarter of 2017 and end in the fourth quarter of 2030.

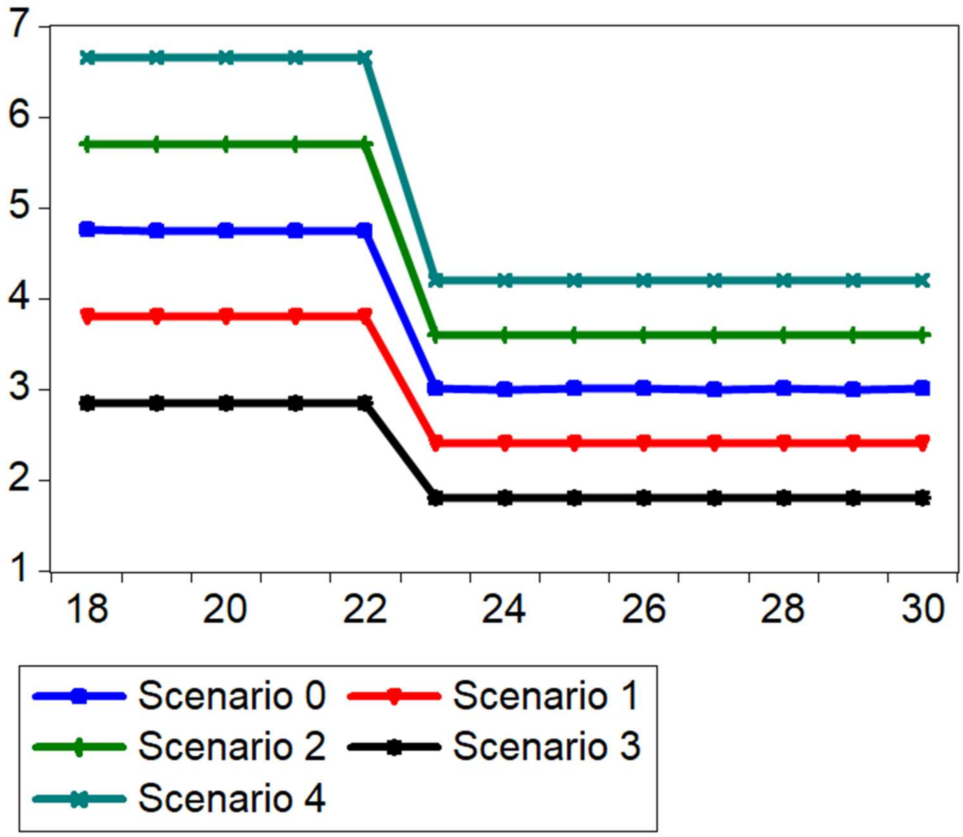

Figure 7: Population scenarios: yearly growth rates of Qatari population. Scenario horizons start in the third quarter of 2017 and end in the fourth quarter of 2030.

By considering all possible combinations of population, GDP and efficiency scenarios, we end up with a very large number of cases. However, GDP and population scenarios must be properly matched as GDP and population growths are linked. In fact, if GDP growth is large and positive, we might postulate a larger population growth given that the Qatari economy will attract foreign workers. In the following section, we focus on specific combinations of GDP and population scenarios, leading to combinations of most relevant interest. We will combine those cases with all the various scenarios of energy efficiency. Other combinations are available for interested readers upon request.

The combinations of GDP and population scenarios we consider are the following:

- Case 1: A sustained growth in both GDP and population, given by the combination of Scenario 1 for GDP and Scenario 4 for population; this is a positive overall scenario where GDP growth attracts foreign workers leading to an increase in the population;
- Case 2: A moderate growth in GDP and a reduced growth in population, given by the combination of Scenario 0 for GDP and Scenario 1 for population; in this case, the population growth is reduced due to the limited inflows of foreign workers negatively affected by the less than positive GDP growth;
- Case 3: A reduced growth in GDP and a moderate growth in population, given by the combination of Scenario 3 for GDP and Scenario 2 for population; in this case, the population trend is increasing, but the GDP growth is limited, there is thus a mismatch between the inflows of immigrants and the economic growth of the Qatari economy;
- Case 4: An average growth in GDP and an average growth in population, given by the combination of Scenario 2 for GDP and Scenario 0 for population; in this case, we combine the baseline scenario for population with an average growth scenario for the GDP;
- Case 5: A low growth in GDP and a low growth in population, given by the combination of Scenario 4 for GDP and Scenario 3 for population; this last case corresponds to the negative view on both GDP and population growth.

5. Future electricity consumption in Qatar

Building of the five cases described in the previous section and given the estimated models over the different market segments, we proceed with the construction of the future evolution of electricity consumption. Figures 8 to 13 report the path of the scenario-based forecasts without accounting for the possible role of energy efficiency improvements. Therefore, these figures represent the baseline case to evaluate the role of energy efficiency in controlling, or even reducing, the total predicted energy demand in the medium-long run.

We first note that Case 4, the average scenario, provides forecasts which lie in the middle of the five cases we consider, a somewhat expected finding. When focusing on Case 4 and on the percent increase in electricity consumption with respect to 2016, see Table 4, we observe how, in some market segments, by 2030 the increment, despite significant, will not be extreme. In the GOV case, the increase will be around 95%. For FLAT the increase amount at 80%, 131% for the HOTEL case, and 137% for the VILLA case. For the two remaining segments, we obverse much larger increases in energy consumption: for both the COMM and the IND segments, we observe an increase above 300% in Case 4. These two huge increases are extremely worrying as, in 2016, the two segments cover about the 50% of the total yearly energy consumption of Qatar. Moving away from Case 4, we note that Case 2 and Case 3, which focus on a moderate (reduced) growth in GDP and a reduced (moderate) growth in population, provide future consumption patterns quite close to those of Case 4. For the VILLA segment, the difference is minor, a 9% decrease in Case 2 and a 6% increase in Case 3, while for IND we observe the largest difference, plus 34% in Case 2 and minus 45% in Case 3. Notably, and compared to Case 4, we note that electricity consumption increases (decreases) in Case 2 (Case 3) for IND, while in all other segments Case 2 leads to a decrease in electricity consumption. We link this to the different sizes of the elasticities for IND. In fact, the IND case is the only one where GDP elasticity is higher than the elasticity with respect to the population, and Case 2 considers a larger growth in GDP compared to Case 3. Cases 1 and 5 are extreme, corresponding to sustained (Case 1) or low (Case 5) growth in both GDP and population. In the positive case, both COMM and IND show huge increases in the electricity consumption compared to 2016: a 460% increase for IND and a 570% increase for COMM. For VILLA and HOTEL, the increase is about 200%, while increases for GOV and FLAT are observed at 142% and about 100%, respectively. In the negative case, the increase is limited for COMM and IND, less than 200%. Therefore, future electricity consumption appears to be extremely sensitive to the economic drivers, and there is a risk that, in positive scenarios, electricity consumption increases in a marked way. Therefore, evaluating the possible benefits of energy efficiency improvements is crucial.

Table 4: Increase in yearly electricity consumption compared to the consumption in 2016

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 4	Case 5
	COMM					FLAT				
2020	81%	62%	70%	66%	56%	26%	20%	23%	22%	18%
2025	276%	164%	194%	182%	112%	62%	40%	50%	46%	30%
2030	569%	298%	345%	327%	162%	100%	62%	76%	69%	42%
	GOV					HOTEL				
2020	48%	32%	41%	37%	27%	37%	27%	32%	29%	23%
2025	94%	55%	78%	66%	41%	116%	70%	89%	80%	50%
2030	142%	76%	116%	95%	55%	206%	114%	147%	131%	72%
	IND					VILLA				
2020	58%	74%	56%	65%	78%	39%	33%	35%	34%	31%
2025	237%	198%	168%	188%	148%	117%	79%	90%	86%	60%
2030	461%	349%	270%	315%	191%	204%	128%	143%	137%	81%

The table reports the scenario-based increase in electricity consumption in each market segment for the five cases described at the end of Section 4. The table measures the increase at the yearly level (cumulated quarterly electricity consumption in each year) compared to the total electricity consumption observed in 2016, and without any improvement in energy efficiency. The table reports a comparison on selected years.

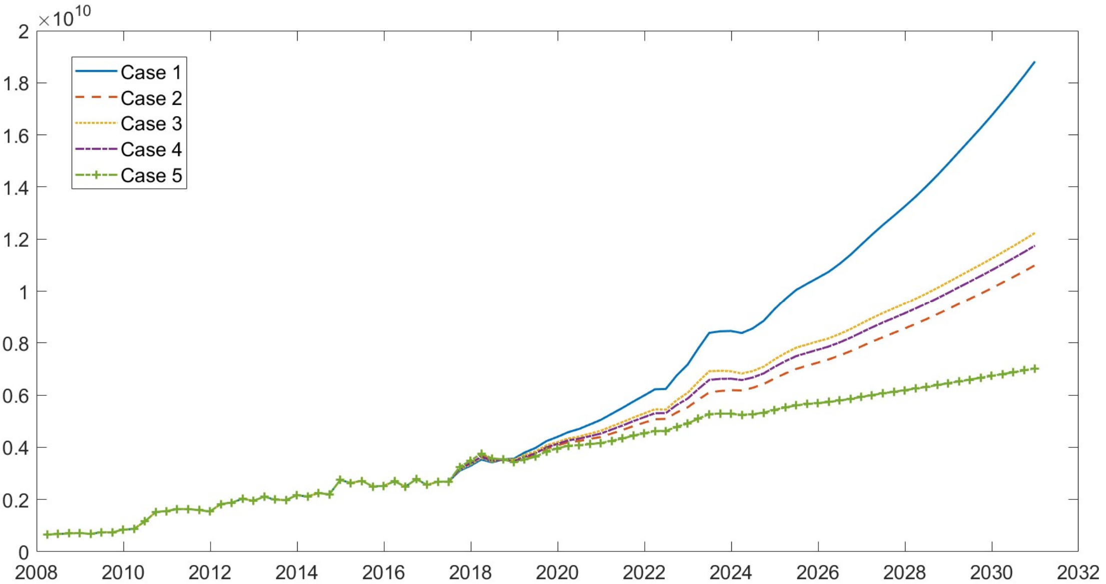

Figure 8: Scenario-based electricity consumption forecasts for COMM in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

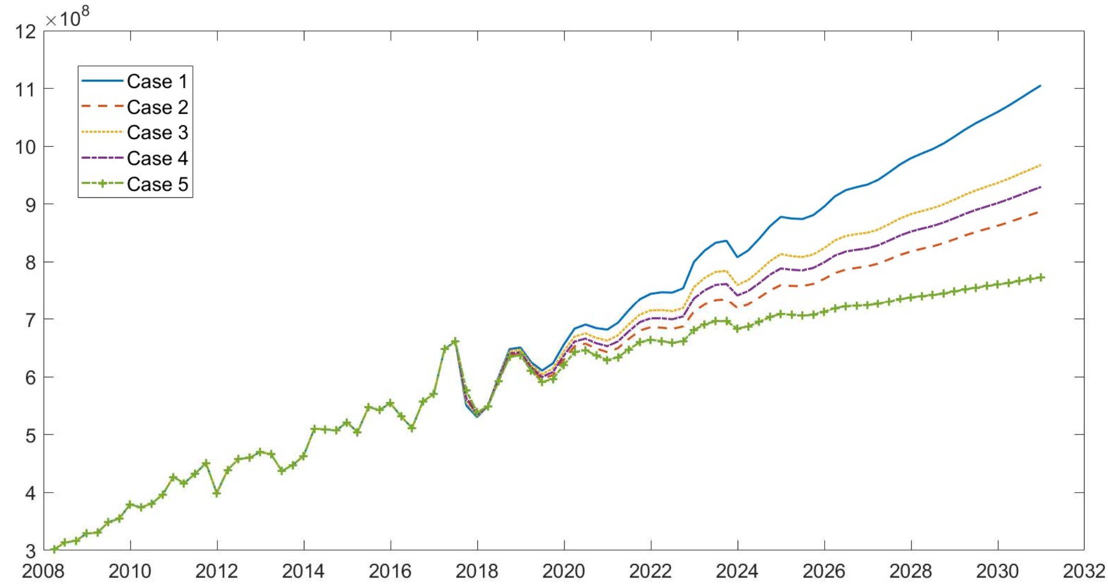

Figure 9: Scenario-based electricity consumption forecasts for FLAT in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

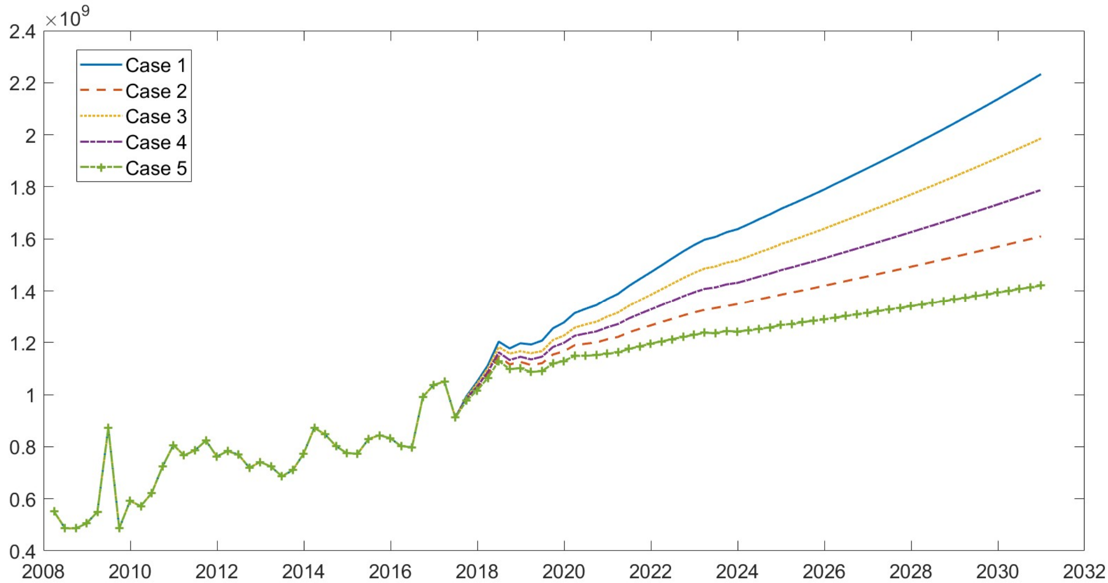

Figure 10: Scenario-based electricity consumption forecasts for GOV in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

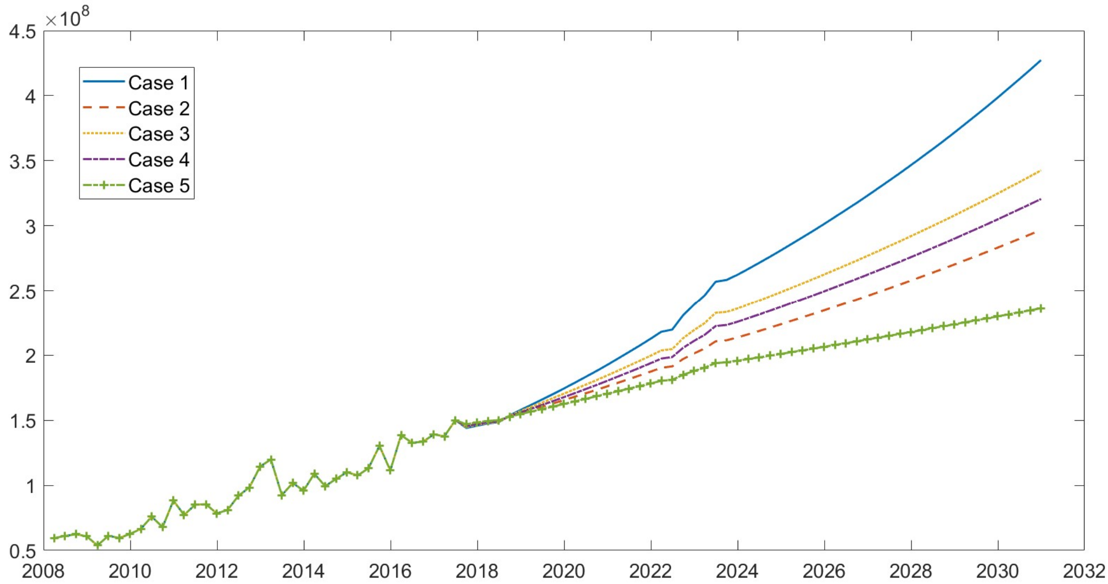

Figure 11: Scenario-based electricity consumption forecasts for HOTEL in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

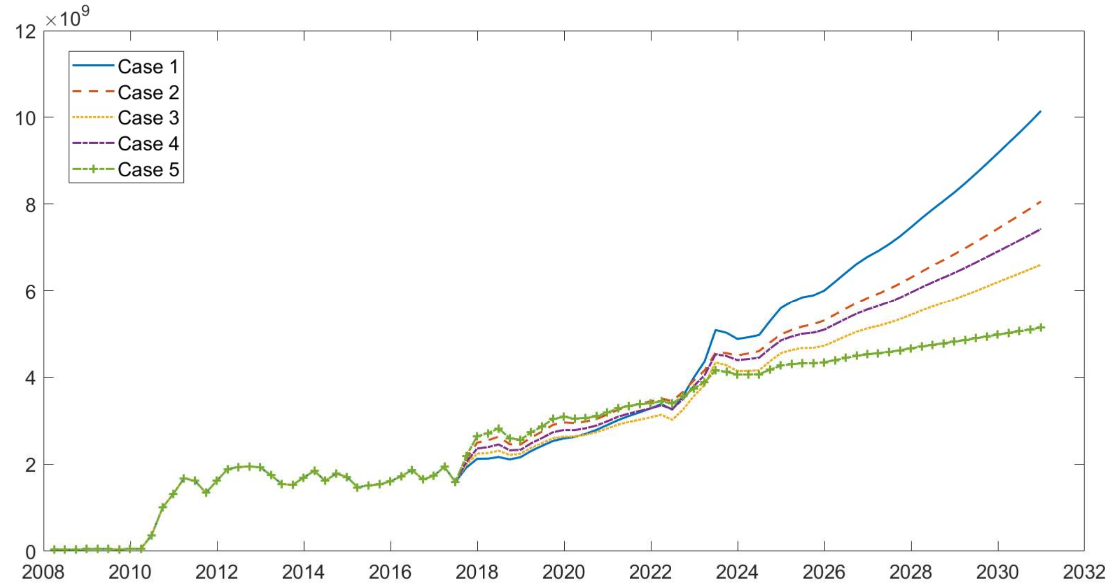

Figure 12: Scenario-based electricity consumption forecasts for IND in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

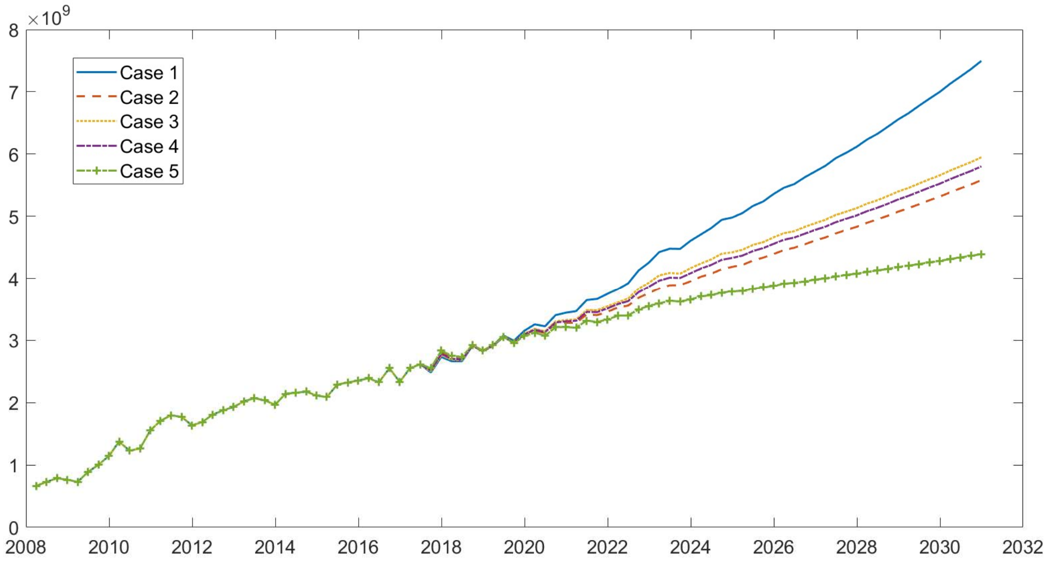

Figure 13: Scenario-based electricity consumption forecasts for VILLA in kWh – the five cases correspond to the combination of GDP and population scenarios as described at the end of Section 4. Scenarios-based forecasts start from the first quarter of 2017 and end at the fourth quarter of 2030.

To provide an evaluation of this last aspect, we run two different simulations. In the first case, we analyze the long-run effect of a 1% (5%) decrease in the elasticities of both GDP and population. We measure the long-run effect as the percentage decrease in electricity consumption compared to the values observed in 2016. Table 5 reports the results, which are extremely interesting and positive, particularly for the COMM and IND market segments. In those markets, a 5% increase in energy efficiency (as proxied by the elasticities) lead to a contraction of electricity consumption of more than 40% (42% for COMM and 52% for IND). In the other market segments, the contraction is smaller but still remarkable with a minimum contraction of 5% in the GOV segment. Comparing the contraction in electricity consumption after a 5% reduction in elasticities, and the contraction after a 1% reduction, we note an almost linear relation. Therefore, we might postulate that a 10% improvement in energy efficiency might lead to a sensible reduction in total electricity consumption. The second simulation we run focuses on the energy efficiency scenarios. We now compare Case 4, the average scenario for GDP and population, a baseline scenario for energy efficiency, i.e. no improvement in efficiency, with the three scenarios for energy efficiency improvement described in

Section 4. We label the energy efficiency scenarios as E-2, E-3 and E-4, while we also refer to Case 4 as energy efficiency scenario E-1.

Table 6 reports the evaluation of energy efficiency improvements by comparing the contraction to both Case 4, as well as to the electricity consumption observed in 2016. In some market segments, especially GOV, the introduction of energy efficiency improvements has a minor impact, leading, at maximum, to a 15% decrease in electricity consumption, compared to Case 4 in 2030. . Differently, in the other segments, the decrease compared to Case 4 is much larger, particularly for COMM and IND, as expected. Notably, by improving energy efficiency, we could lead to sensible drops in electricity consumption, with a 70% decrease in 2030 compared to Case 4. With respect to 2016 electricity consumption, and assuming an increase in both GDP and population at a moderate/average level, the introduction of energy efficiency improvements might lead to a reduced increase in total electricity consumption. More interestingly, in the IND case, a relevant increase in energy efficiency might even lead to a reduction of electricity consumption. The results show that energy efficiency improvements have a fundamental role in controlling the evolution of electricity consumption over time. We stress that these simulations do not account for the possible rebound effect. Nevertheless, the simulation evidence supports the implementation of energy efficiency improvement policies. The appendix includes figures reporting time evolution of electricity consumption conditional to energy efficiency improvements.

Table 5: Long-run contraction of electricity consumption

	1%	5%
COMM	-10%	-42%
FLAT	-3%	-14%
GOV	-1%	-5%
HOTEL	-4%	-19%
IND	-14%	-52%
VILLA	-6%	-27%

The table reports the contraction (on a yearly basis) of electricity consumption conditional to a joint decrease in the elasticities to GDP and population as in the first row. We measure the contraction under the long-run consumption levels coherent with the end of 2016 GDP and population levels (i.e. assuming a zero-growth rate for GDP and population and let the electricity consumption converge to the steady state).

Table 6: Change in electricity consumption with efficiency improvements

		Change w.r.t. Case 4			Change w.r.t. 2016			
		E-2	E-3	E-4	Case 4	E-2	E-3	E-4
COMM	2020	-5%	-21%	-21%	66%	58%	31%	31%
	2025	-11%	-45%	-57%	182%	151%	56%	22%
	2030	-12%	-46%	-71%	327%	277%	131%	25%
FLAT	2020	-2%	-8%	-8%	22%	20%	12%	12%
	2025	-3%	-15%	-22%	46%	41%	23%	13%
	2030	-3%	-16%	-30%	69%	63%	42%	19%
GOV	2020	0%	-2%	-2%	31%	31%	28%	28%
	2025	-1%	-7%	-9%	59%	57%	48%	44%
	2030	-2%	-8%	-15%	85%	82%	71%	58%
HOTEL	2020	-2%	-8%	-8%	23%	21%	14%	14%
	2025	-4%	-21%	-27%	63%	56%	30%	19%
	2030	-5%	-21%	-38%	106%	96%	62%	27%
IND	2020	-5%	-24%	-24%	65%	56%	26%	26%
	2025	-14%	-53%	-65%	188%	147%	34%	2%
	2030	-14%	-54%	-79%	315%	255%	90%	-13%
VILLA	2020	-2%	-10%	-10%	34%	32%	21%	21%
	2025	-6%	-28%	-36%	86%	74%	33%	20%
	2030	-7%	-30%	-50%	137%	121%	67%	18%

The table reports the change in electricity consumption, on a yearly basis, with respect to reference periods. All simulations consider the scenarios for Case 4 and add to these scenarios for GDP and population, the possible scenarios for the improvement in energy efficiency. In columns 3 to 5, we report changes with respect to the yearly consumption under the scenarios of Case 4, in the absence of efficiency improvements. In columns 6 to 9, we report changes with respect to the consumption in 2016. For comparison purposes, we report in column 6 the change under Case 4.

6. Conclusions and policy recommendations

This study analyzes the nexus between electricity consumption, population growth and GDP growth in Qatar. We observe a clear relation among these variables, a coupling that will continue for decades and will have consequences on the growth and development paths of the country. These aspects interact with the development plan of Qatar as outlined in the QNV2030 vision.

The empirical and simulation-based evidences we provide highlight that an efficient use of electricity is a crucial element for improving the efficient use of economic resources. The forecasting scenarios provide evidence suggesting that a 5% improvement in the efficient use of electricity, as proxied by a decrease in the elasticity of electricity consumption to population and GDP growth, lead to relevant electricity consumption reduction. In fact, we find a reduction in electricity consumption from 52% and 42% in the industrial and commercial market segments, respectively, down to 5% in the government and public sector market segments.

Achieving electricity efficiency improvements is thus crucial for controlling the evolution of the demand side of the electricity market and require proper energy policies. The Qatari government has already adopted several measures. For instance, the energy conservation and efficiency program, TARSHEED, at KAHRAMAA. To further improve electricity efficiency, this program should be further supported and prolonged, but complementary strategies should accompany it. Examples are the development of auditing processes specific to each market segment to control the implementation of electricity efficiency practices, for instance in new building construction and in the choice of appliances for new buildings. Furthermore, electricity saving policies should involve the customers, pointing at the adoption of electricity saving behaviors in the long run.

However, to improve electricity efficiency in a relevant way, the government should evaluate price reforms, as they represent a key component for the adoption of electricity efficiency by final consumers. In fact, the adoption of flat tariffs does not induce final consumers to develop electricity saving behaviors. This is also consistent with the evidence in Kohler (2014) and Matter et al. (2017). These aspects, despite being crucial for the design of future energy policies, would require additional analyses going beyond the scope of the present paper.

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A. Monthly electricity consumption and data reconciliation

Visual inspection of the graphs in Figure 1 highlights several anomalies in the official (original) data, due to possible misalignment between the consumption period and the billing period (see Section 2.1). In what follows, we explain how we adjust the most evident anomalies in the original data, to recover realistic infra-annual temporal dynamics of the series, unaffected by possible weakness in the collection of the source data.

First of all, we register that the level of electricity consumption of the Industrials (IND) segment in the period 2008-2010 is very low, as compared to what happened from 2011 onwards. However, because we have no information about possible reasons for that, the monthly IND data for 2008-2010 are not adjusted.

In addition, the April 2009 value in the GOV series seems not in line with the behavior of that series in the closer periods, but even in this case no information on possible causes is available, so we decided to leave this value untouched.

Finally, clear data anomalies appear in the months belonging to the third quarters of years 2013, 2014, and 2015 for FLAT, VILLA and TOTAL series, where peaks and troughs are by far more pronounced than the previously registered seasonal patterns. In addition, HOTEL and GOV series present anomalies in the 2013 third quarter's monthly data. In these last cases we adopt a simple adjustment procedure for the component series FLAT, GOV, HOTEL and VILLA, by this way indirectly recovering the adjusted TOTAL series, which is obtained by summing the adjusted component series.

The adjustment procedure moves from the observation of the quarterly series (Figure 3). Apart IND, the other six series present a positive trend, with a clear seasonal pattern superimposed, whose amplitude is generally stable, with the only exception of VILLA. In addition, COMM series presents a shift passing from year 2009 to year 2010, which affects in the same way the TOTAL series as well.

The adjusted values for the July, August and September in years 2013, 2014 and 2015 for FLAT and VILLA are obtained by temporally disaggregating the correspondent third quarters' data through the monthly average shares calculated using 2012 and 2016 data for that quarter, when the behavior of these series is considered 'regular', in order to get a more sensible temporal dynamics than the observed ones (Figure A.1).

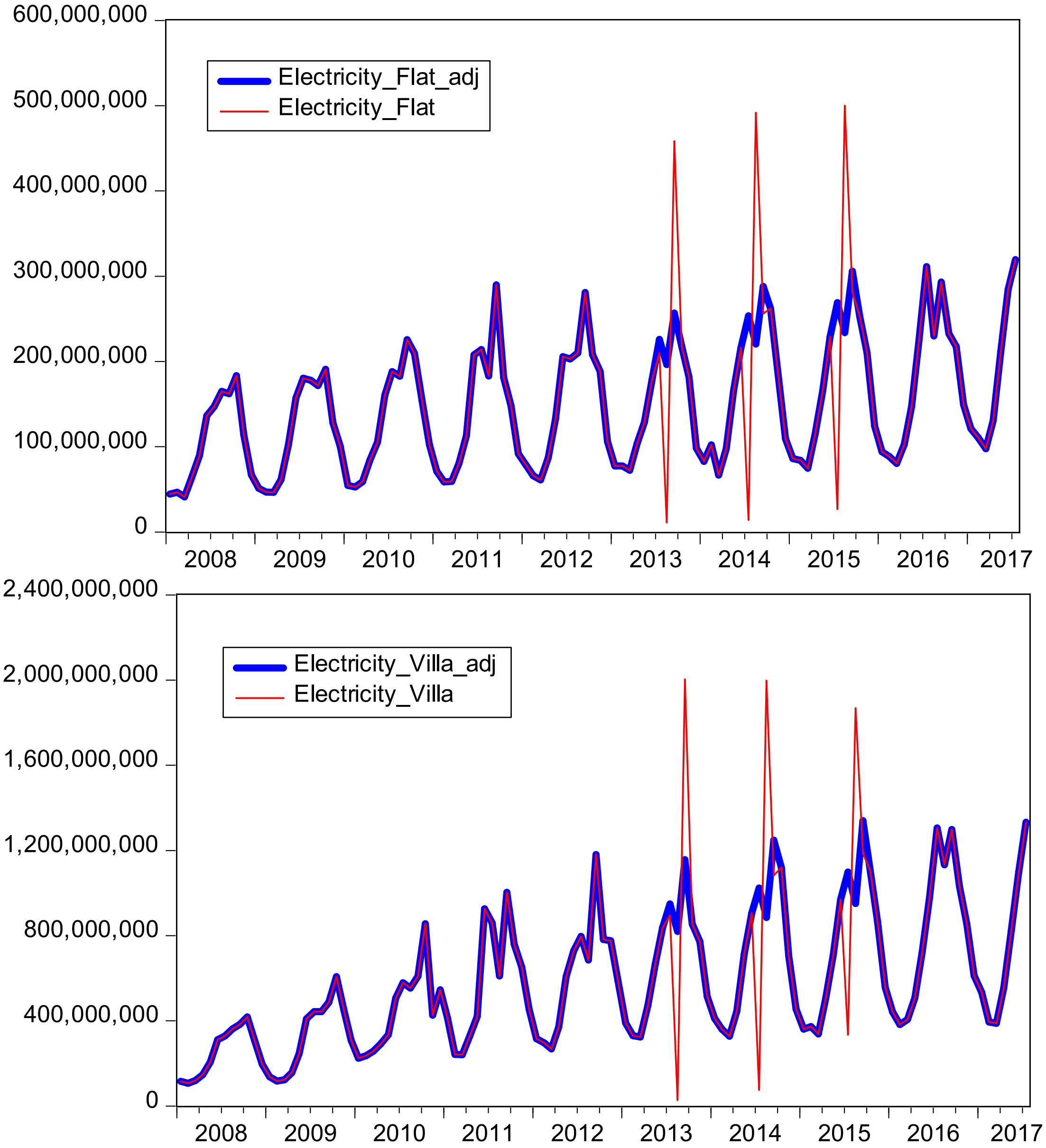

Figure A.1. Original and adjusted monthly series of Qatari electricity consumption by market segments: FLAT (upper panel) and VILLA (lower panel).

As for the HOTEL and GOV series, only the values for July, August and September 2013 are adjusted, by temporal disaggregation of the third quarters' values using the relevant monthly average shares in 2012 and 2014 (Figure A.2).

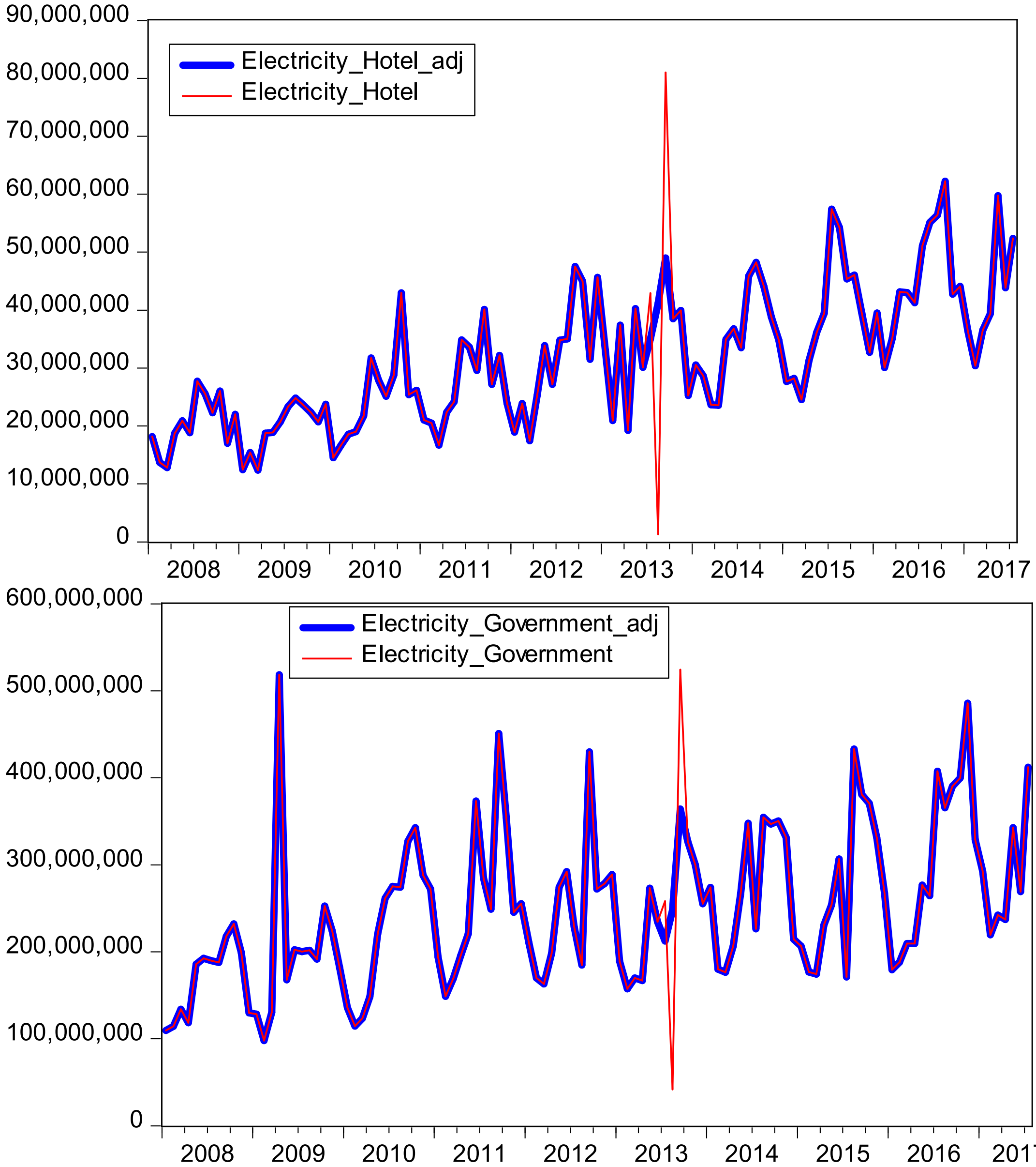

Figure A.2. Original and adjusted monthly series of Qatari electricity consumption by market segments: HOTEL (upper panel) and GOV (lower panel)

Finally, the adjusted monthly TOTAL series is obtained via aggregation of the six component series (the two original and the four adjusted ones, see Figure A.3). It should be noted that in all cases the adjusted monthly series are in line with the relevant (original) quarterly counterparts.

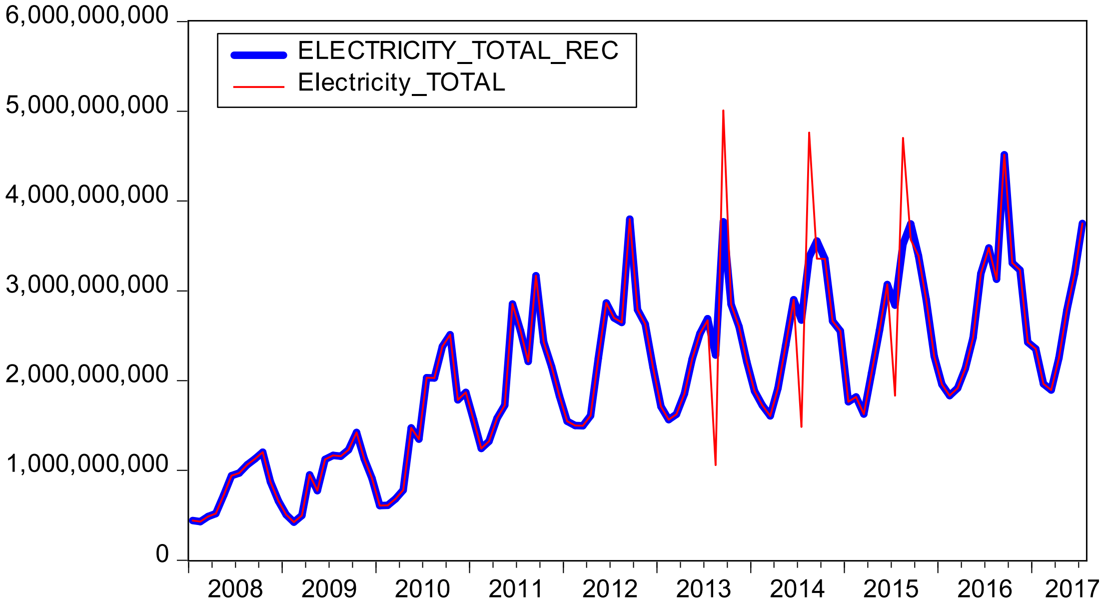

Figure A.3. Original and adjusted monthly series of Total Qatari electricity consumption

B. Figures of electricity consumption patterns with the introduction of energy efficiency improvements

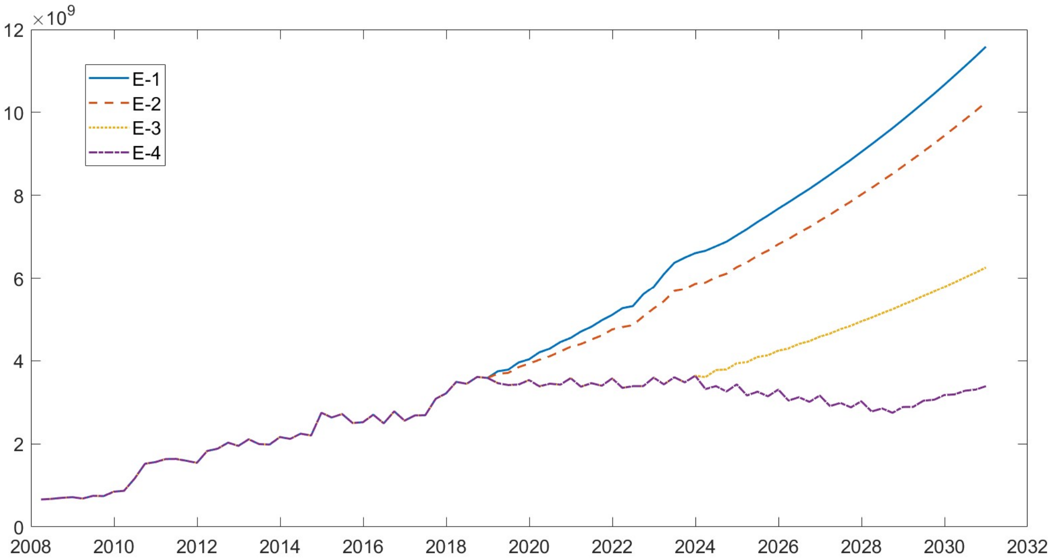

Figure B.1: Scenario-based electricity consumption forecasts for COMM (in kWh) under different energy efficiency scenarios

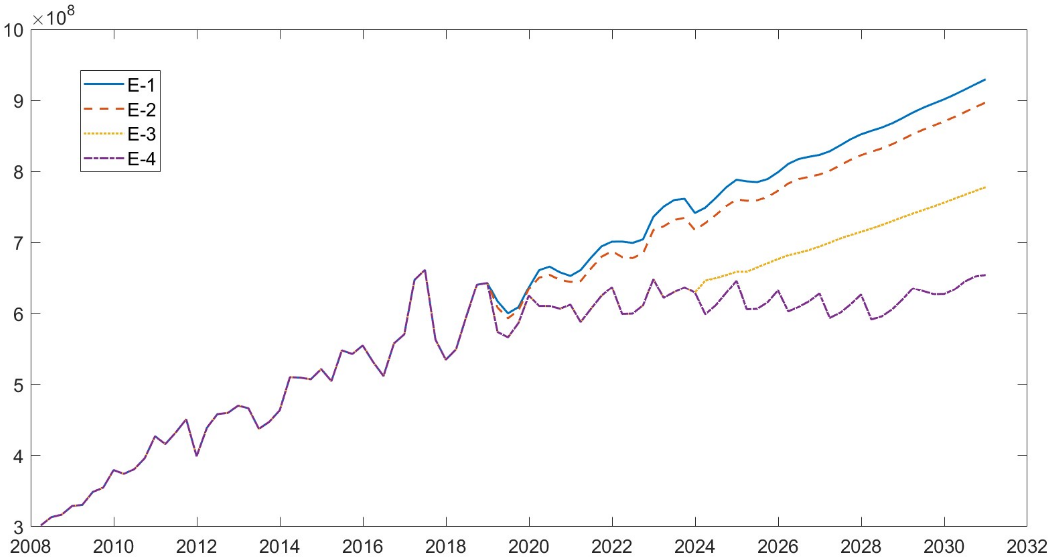

Figure B.2: Scenario-based electricity consumption forecasts for FLAT (in kWh) under different energy efficiency scenarios

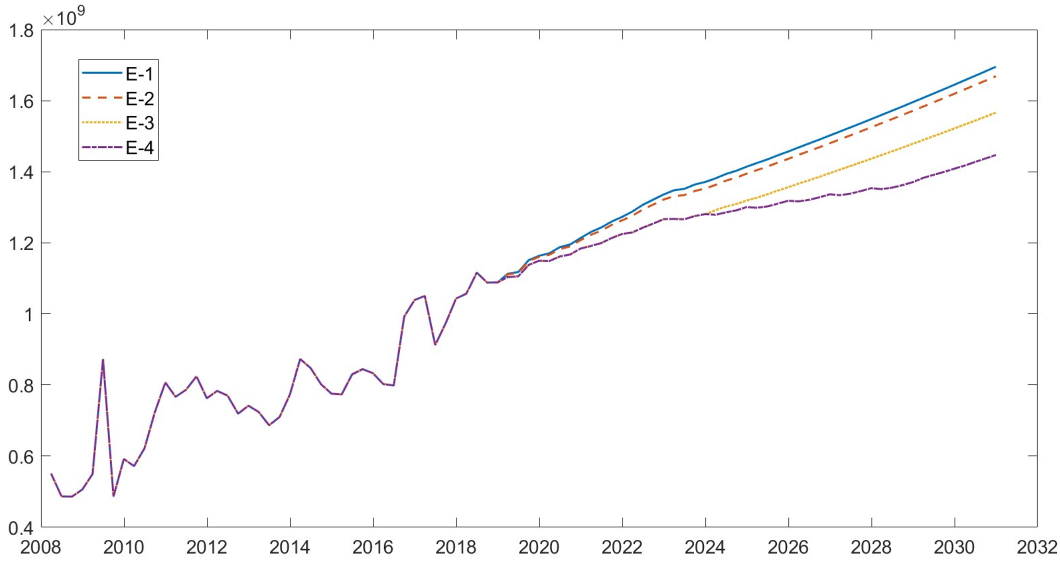

Figure B.3: Scenario-based electricity consumption forecasts for GOV (in kWh) under different energy efficiency scenarios

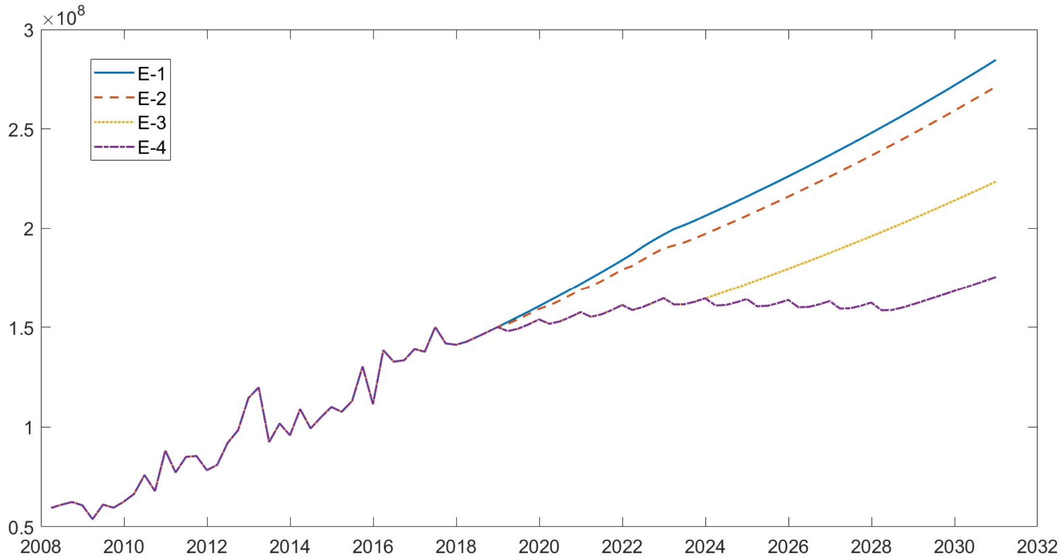

Figure B.4: Scenario-based electricity consumption forecasts for HOTEL (in kWh) under different energy efficiency scenarios

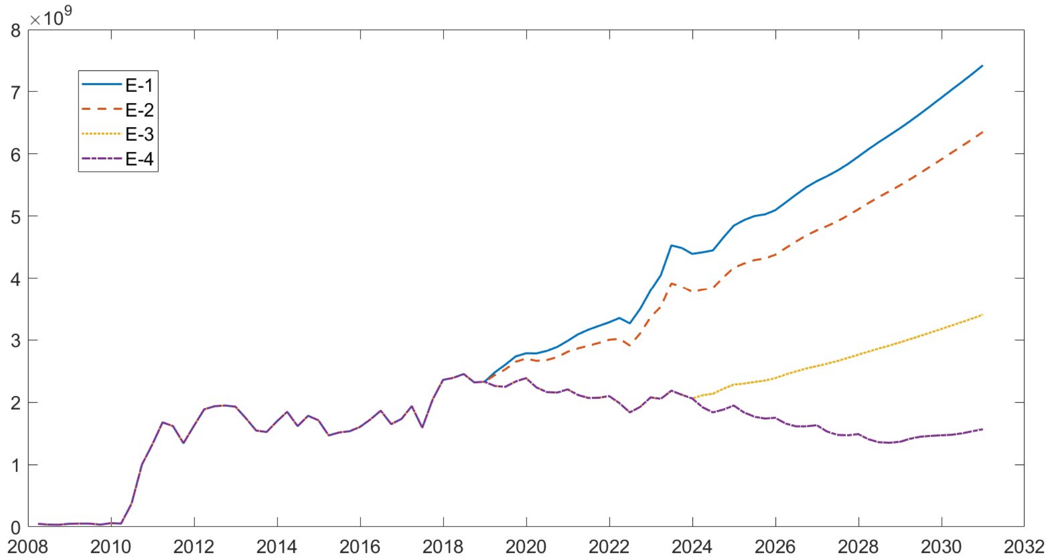

Figure B.5: Scenario-based electricity consumption forecasts for IND (in kWh) under different energy efficiency scenarios

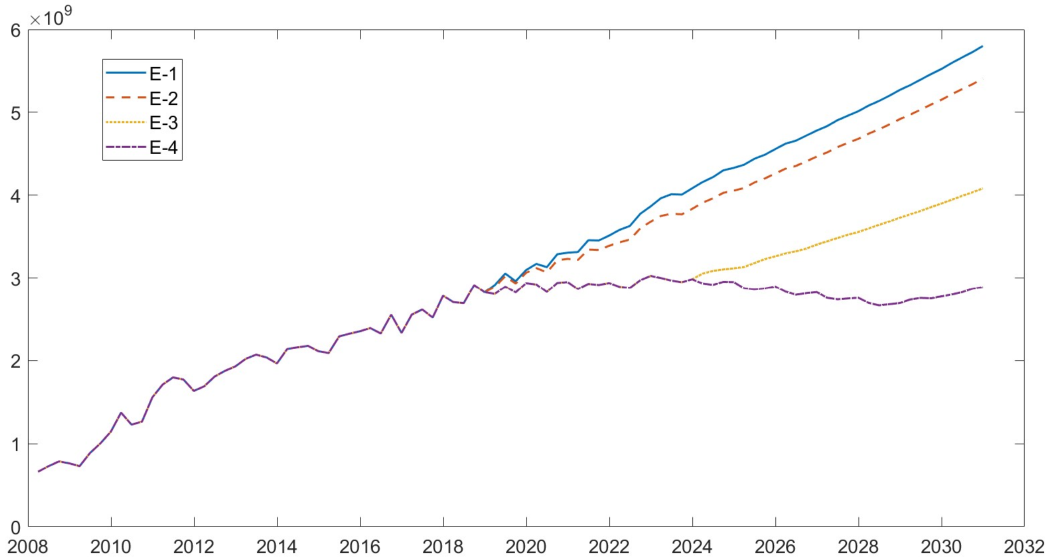

Figure B.6: Scenario-based electricity consumption forecasts for VILLA (in kWh) under different energy efficiency scenarios